Geometry Issues for MDO
(ASCAC Methods Development Peer Review)

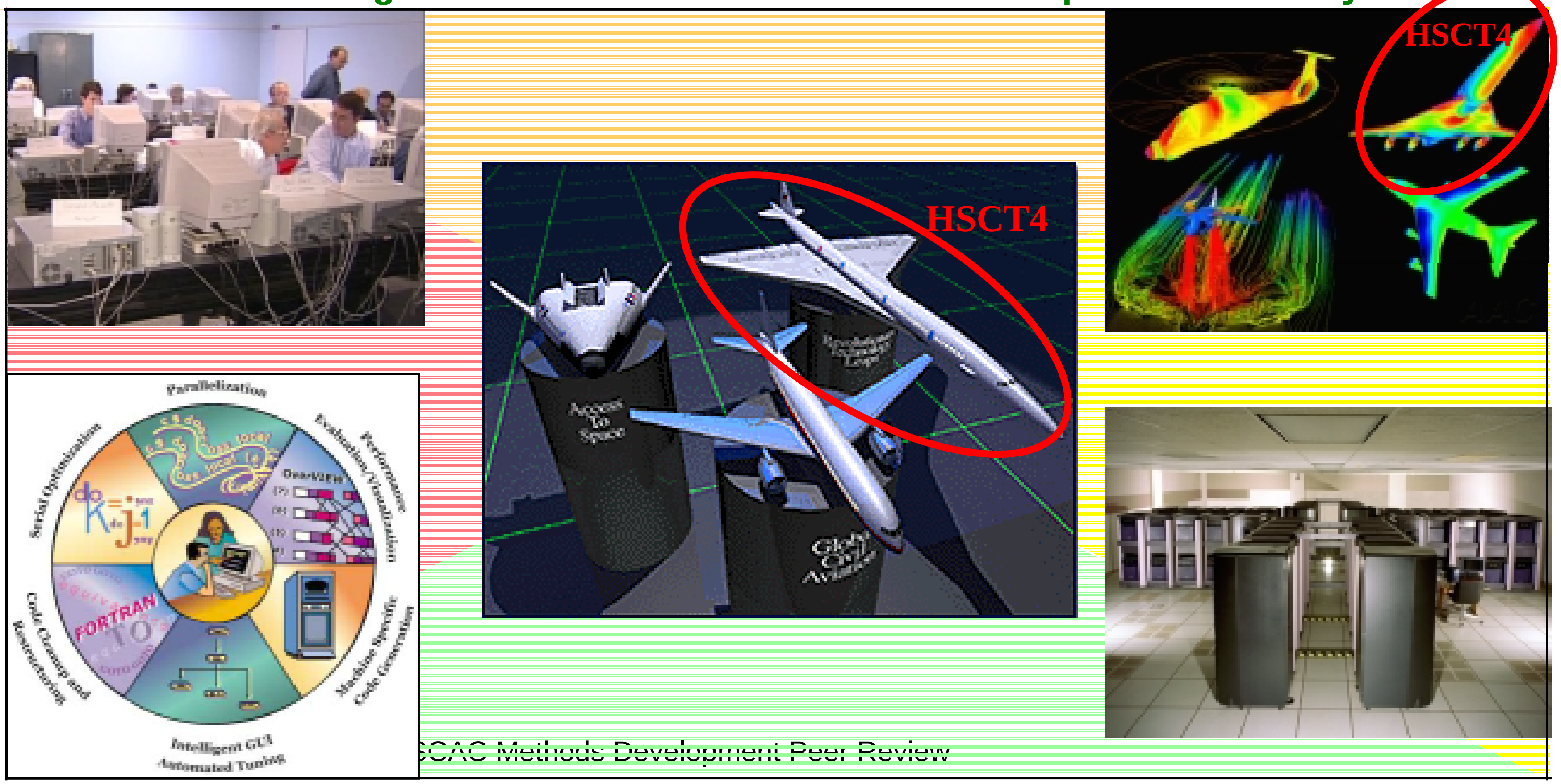
Jamshid A. Samareh

Multidisciplinary Optimization Branch

NASA Langley Research Center

HPCC Program (1992-2001)
(High Performance Computing and Communications)

- **Computational AeroSciences Goal**
  - **Enable improvements to NASA technologies and capabilities in aerospace transportation through the <u>development and application of high-performance computing technologies</u> and the infusion of these technologies into the NASA and national aerospace community**



Why Geometry

Geometry was identified as a high-payoff MDO problem during the 1994 MDORRC Industry Tour.

Here is the verbatim quote:

"High-Payoff MDO Problems:

- *Geometry representations suitable for MDO and which cover the fidelity range (with suitable translators)."*

Objective

Develop shape parameterization tools for high-fidelity MDO applications

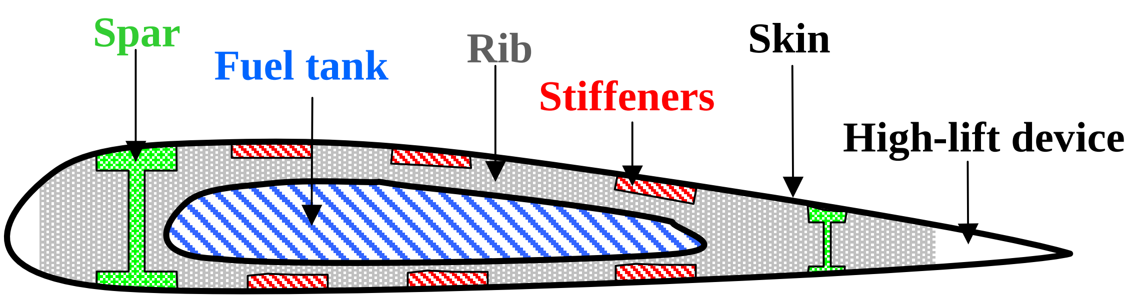
– Identify geometry/grid generation issues of particular importance to MDO

– Balance long term goals against short term requirements

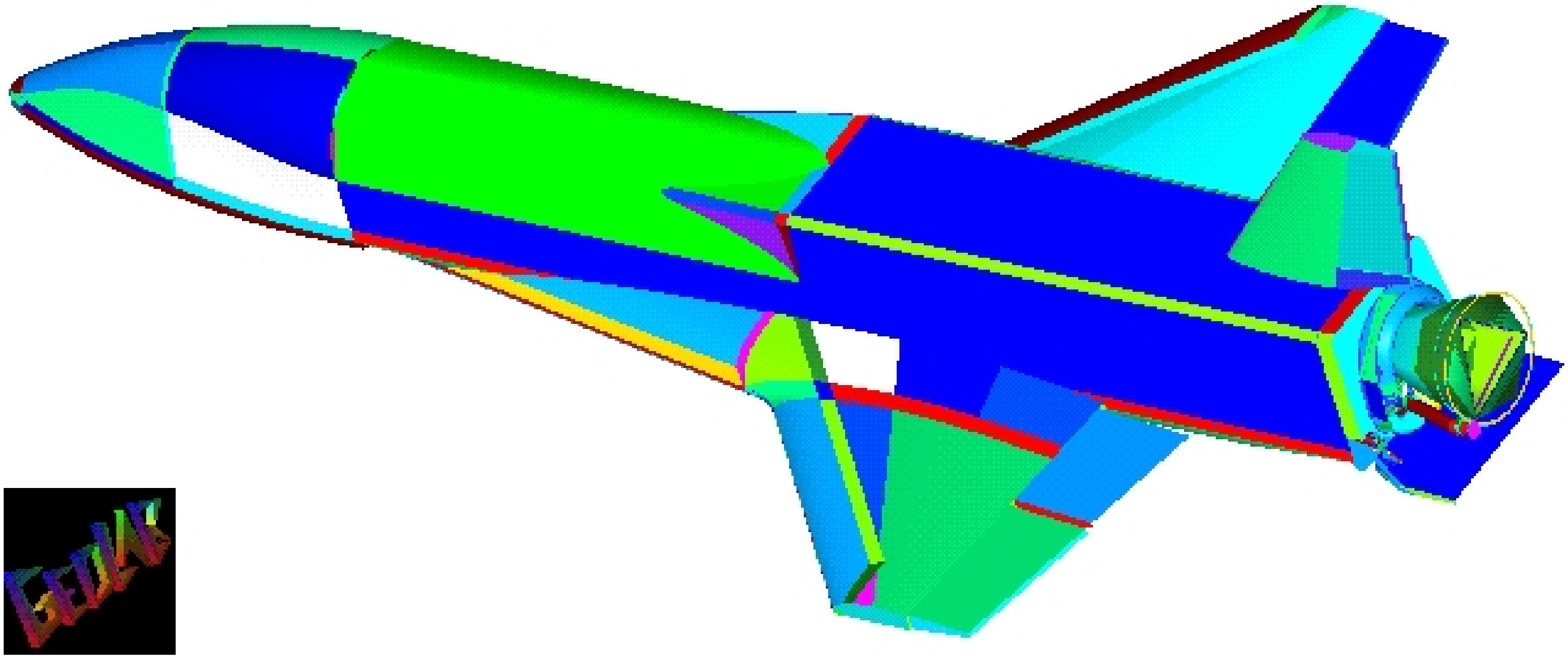
Motivation

High-Fidelity MDO of an aerospace vehicle :

- Has complex geometry with many details
- Requires consistent shape parameterization across all disciplines
- Requires rapid and automatic grid generation tools
- Requires sensitivity derivatives
- Has many disciplines and processes (e.g,. CFD & CSM)

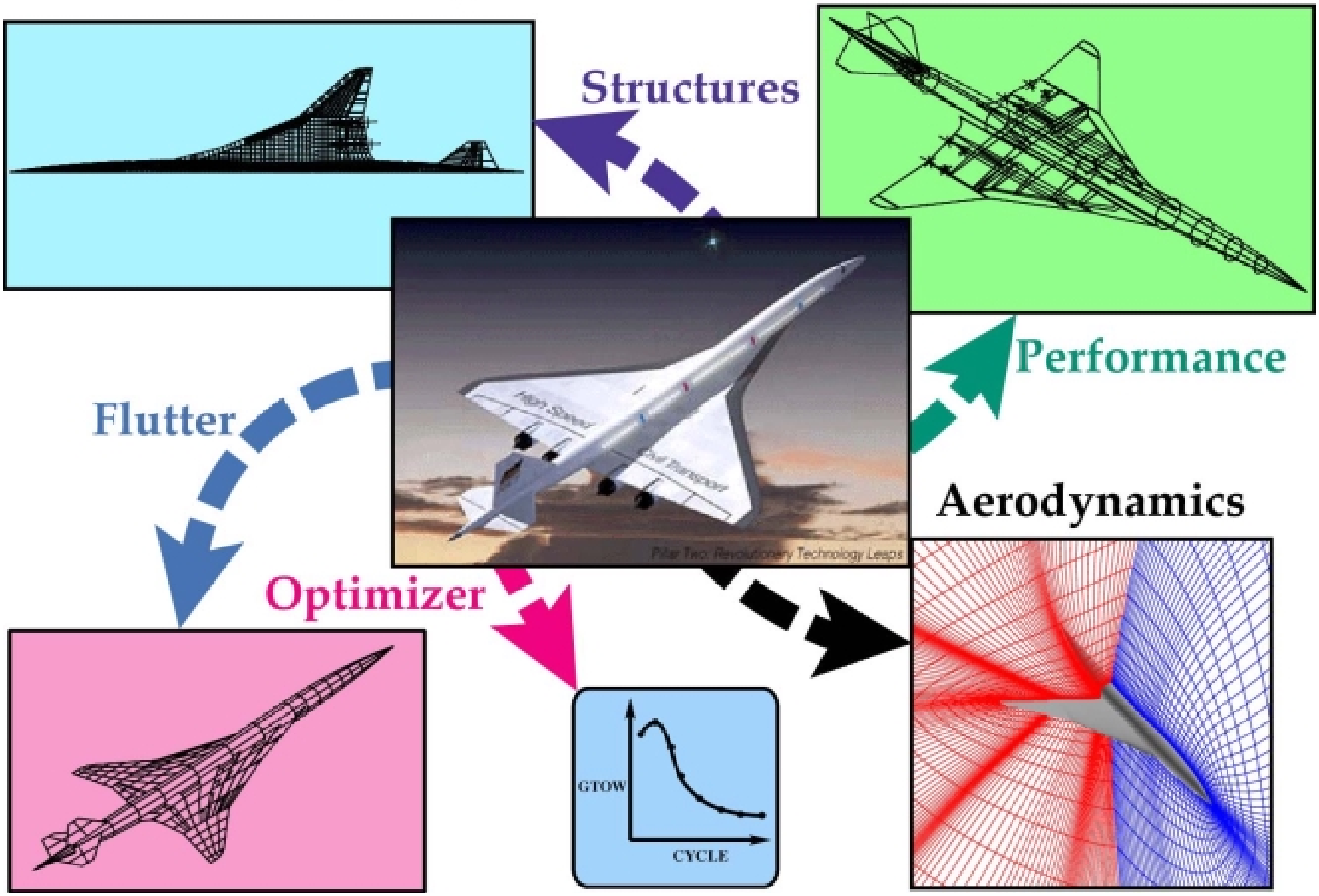


Preliminary Design Geometry
X34 CAD Model

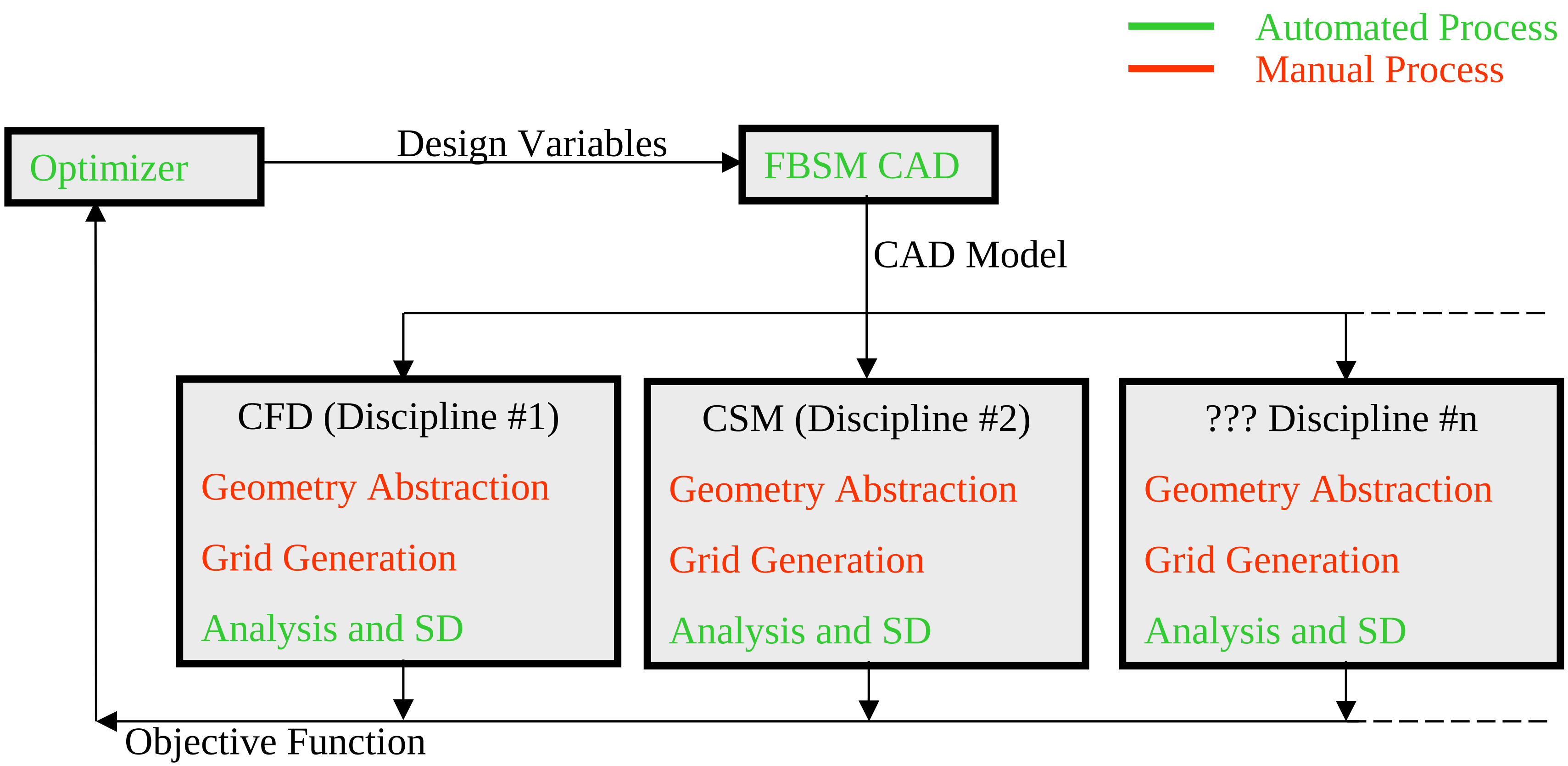


23,555 curves and surfaces

Geometry Models for a High Speed Civil Transport



Long Term CAD-Based MDO Goal
(Current Status)



CAD-Based MDO
(Current Status)

- **Consistent**: Will the process be consistent across multiple disciplines? (Yes)
- **Automatic**: Can geometry abstraction be automated? (No)
- **Grid generation**: Can we generate grids automatically based on a CAD model for all disciplines? (No)
- **Setup time**: How quickly can it be set up? (Days)
- **Compact**: Will it provide a compact set of design variables? 10s vs. 1000s (Yes)
- **Analytical Sensitivity**: Is it feasible to calculate sensitivity data analytically? (No)

Sensitivity Analysis

objective function

(e.g., Stress, C_D)

$$\frac{\partial F}{\partial \bar{\mathrm{v}}} = \underbrace{\frac{\partial F}{\partial \mathrm{Grid}_f}}_{\text{analysis code}} x \underbrace{\frac{\partial \mathrm{Grid}_f}{\partial \mathrm{Grid}_s}}_{\text{field grid generator}} x \underbrace{\frac{\partial \mathrm{Grid}_s}{\partial \mathrm{Geometry}}}_{\text{surface grid generator}} x \underbrace{\frac{\partial \mathrm{Geometry}}{\partial \bar{\mathrm{v}}}}_{\text{geometry modeler (CAD)}}$$

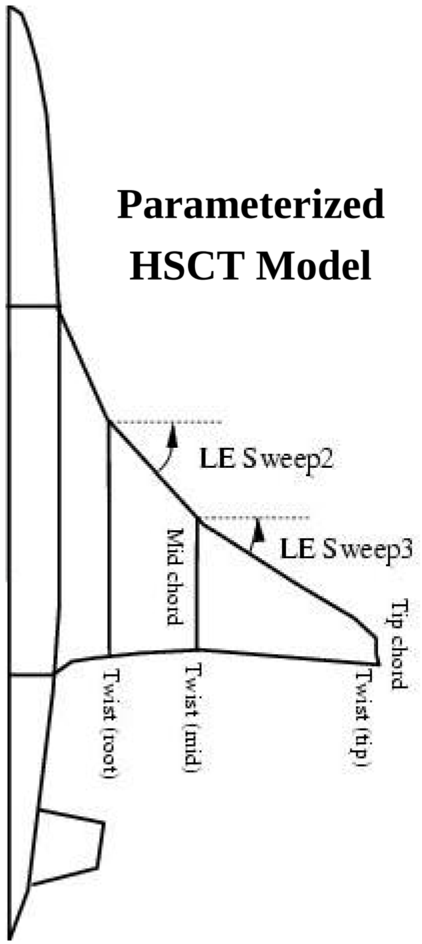
v design variables

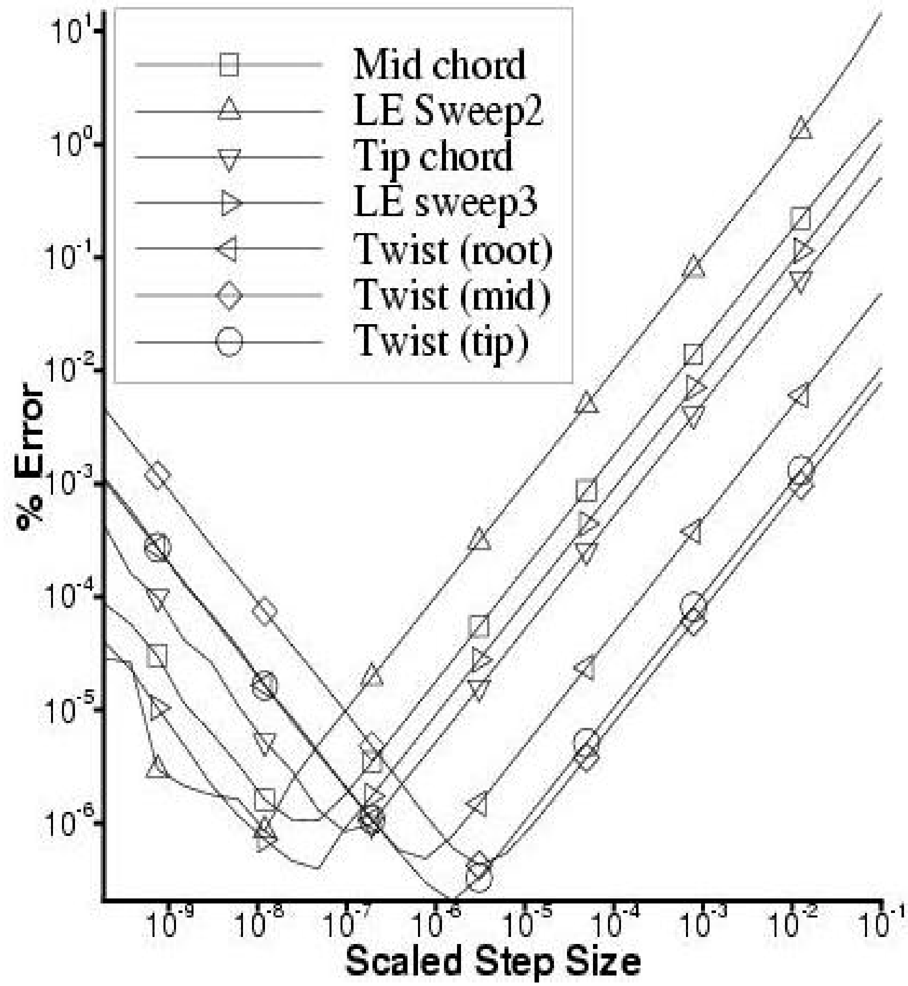
(e.g., span, camber)

- Manual differentiation
- Automatic differentiation tools (e.g., ADIFOR and ADIC)
- Complex variables
- Finite-difference approximations (may not be possible for CAD)

Finite-Difference Approximation Error for Sensitivity Derivatives

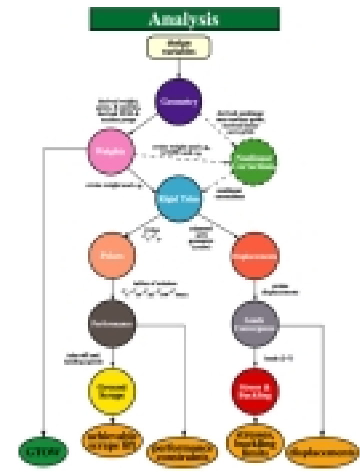
Parameterized HSCT Model

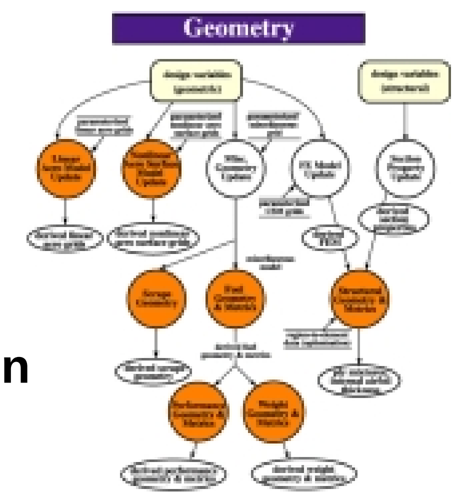




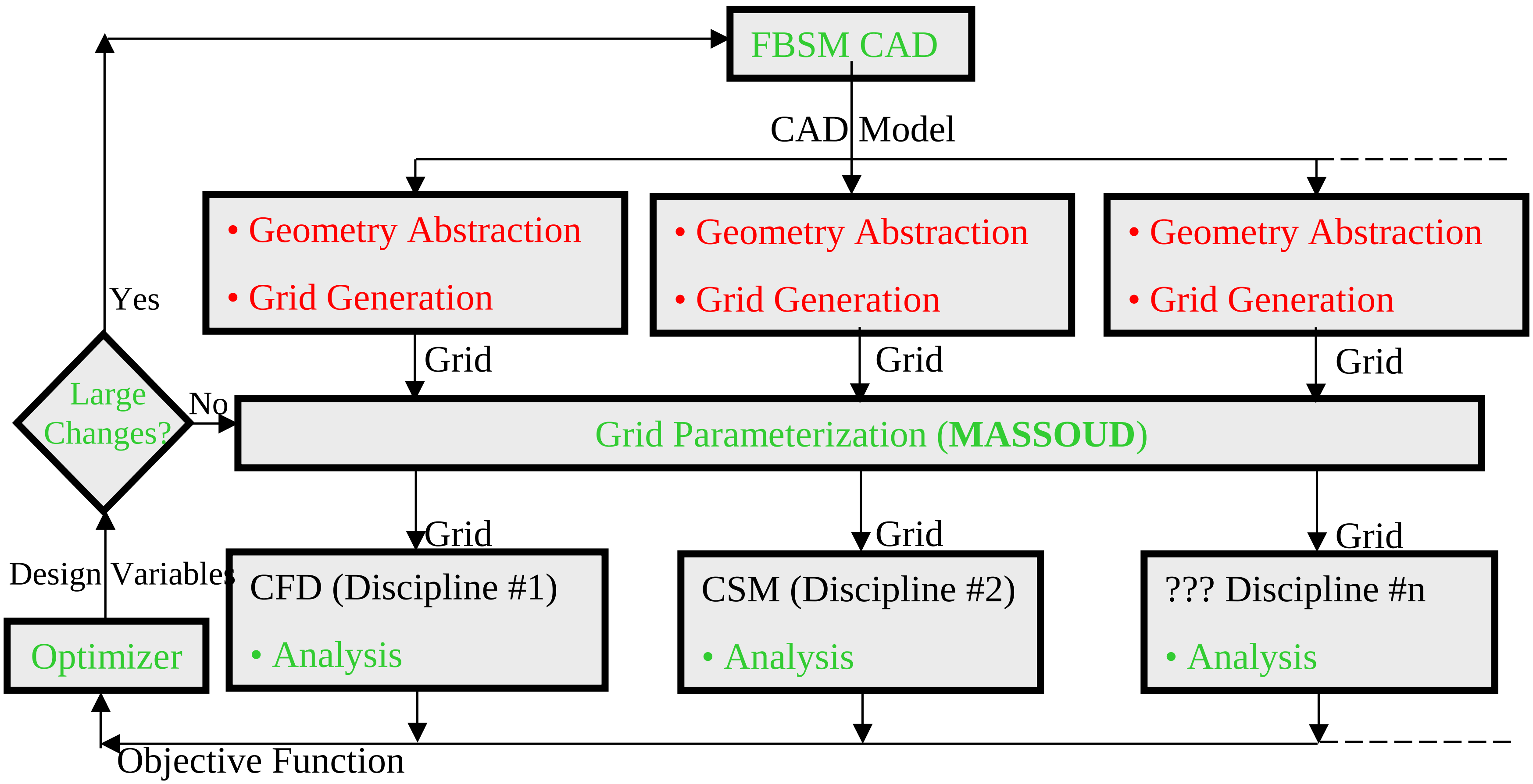
Geometry Modeling Issues for HSCT4
(Short Term Requirements)

- **Existing Non-Parametric CAD and FE Models**
- **Geometry model needs to be parametric**
- **7 different processes need geometry models**
  - Linear aerodynamics (USSAERO)
  - Nonlinear aerodynamics (CFL3D)
  - Finite-element structural analysis (GENESIS)
  - Fuel
  - Weights
  - Performance (FLOPS)
  - Ground Scrape
- **Aero and structural models have different grids**
- **Sensitivity derivatives are needed for optimization**
- **Vehicle deflects under loads**





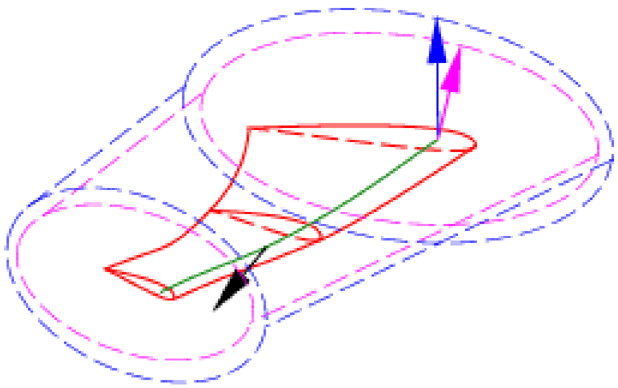
Automated High-Fidelity MDO
(Short Term Requirements)



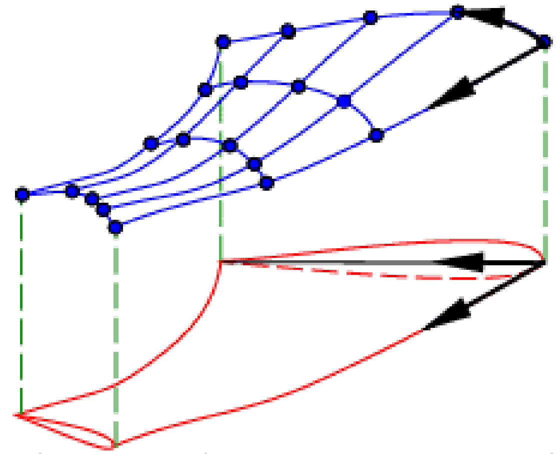
Multidisciplinary Aerodynamic-Structural Shape Optimization Using Deformation (MASSOUD)
(TM-209116, AIAA-2000-4911)

- Parameterizes the changes in shape, not the shape itself (reduces the number of design variables)
- Parameterizes the discipline grids (avoids manual grid regeneration)
- Uses advanced soft object animation algorithms for deforming grids
  - NURBS surface (camber and thickness)
  - Free-form deformation (planform)
  - Nonlinear global deformation (twist and dihedral)

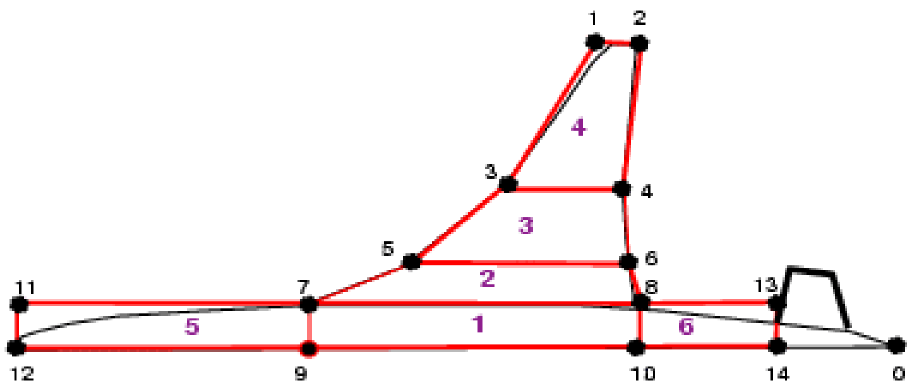
Multidisciplinary Aero/Struc Shape Optimization Using Deformation (MASSOUD)



Nonlinear global deformation
(Twist and Dihedral)



Deformation of parametric NURBS surfaces
(Camber and Thickness)

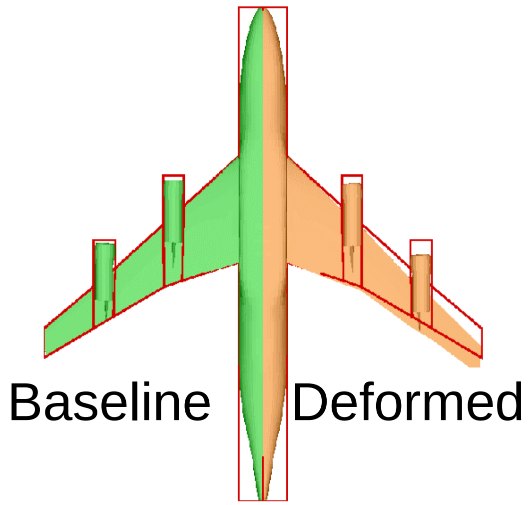


Free–form deformation
(Planform)

MASSOUD (Cont.)

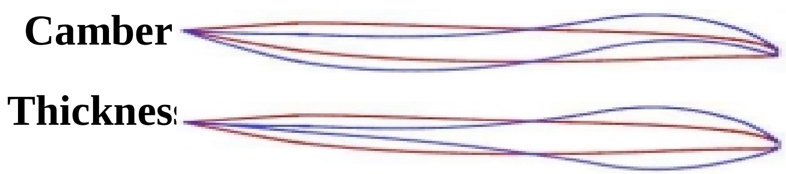
Planform Parameterization

(CFD surface grid of a generic transport)



Camber/Thickness Parameterization

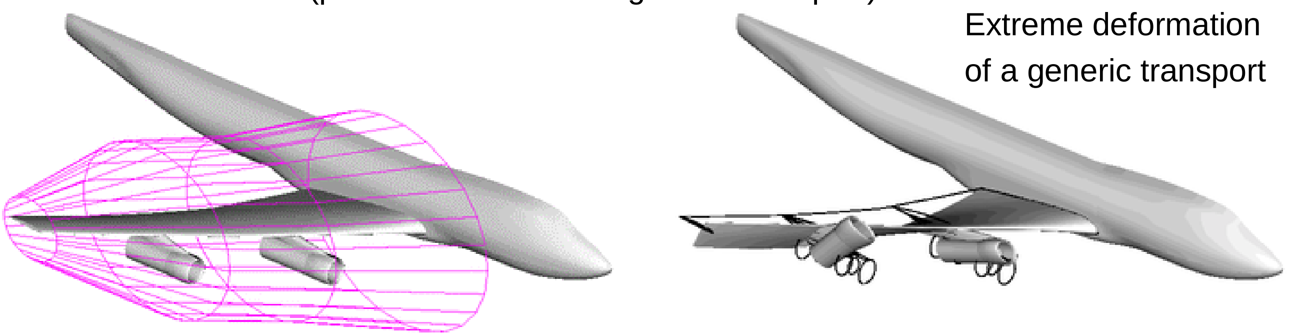
(Airfoil)



Extreme camber & thickness deformation

Twist/Dihedral Parameterization

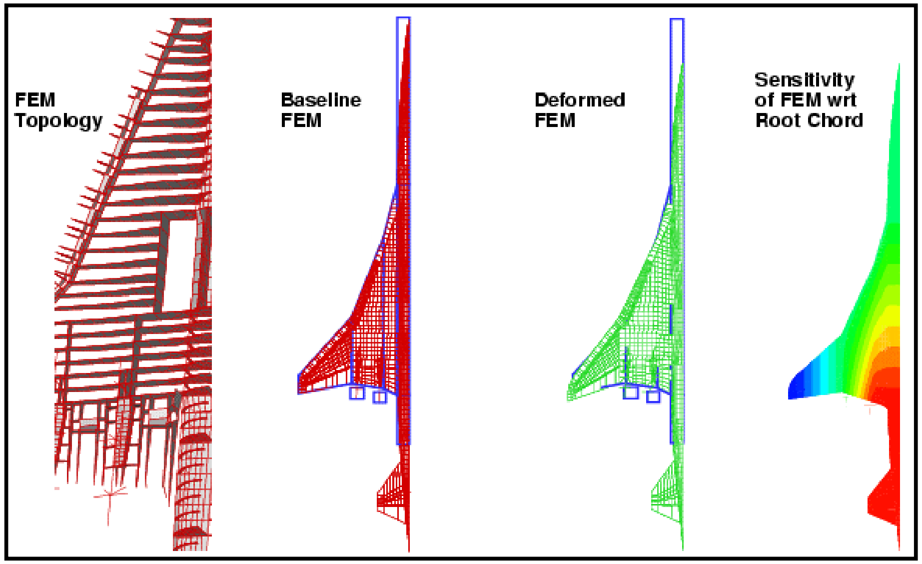
(parameterization of a generic transport)



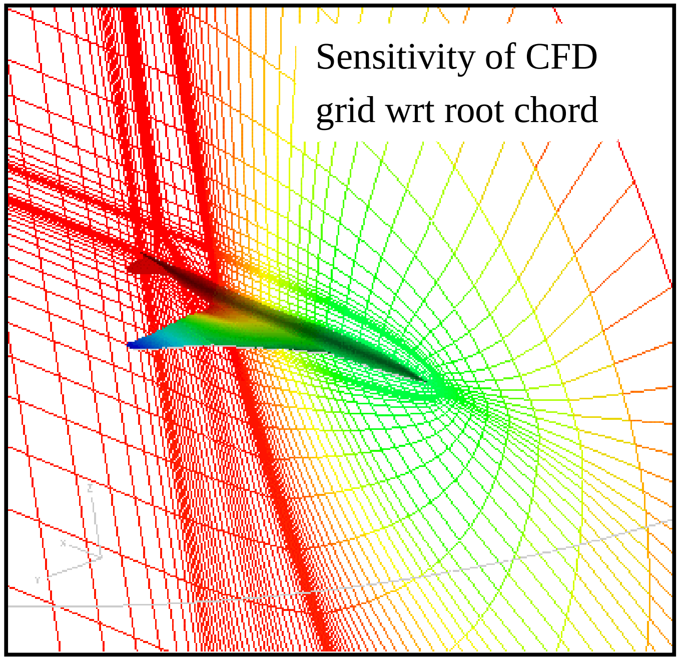
Extreme deformation of a generic transport

Multidisciplinary Shape Parameterization of an HSCT Model (HSCT4)

- Automated process
- 27 aerodynamic shape design variables
- Analytical sensitivity



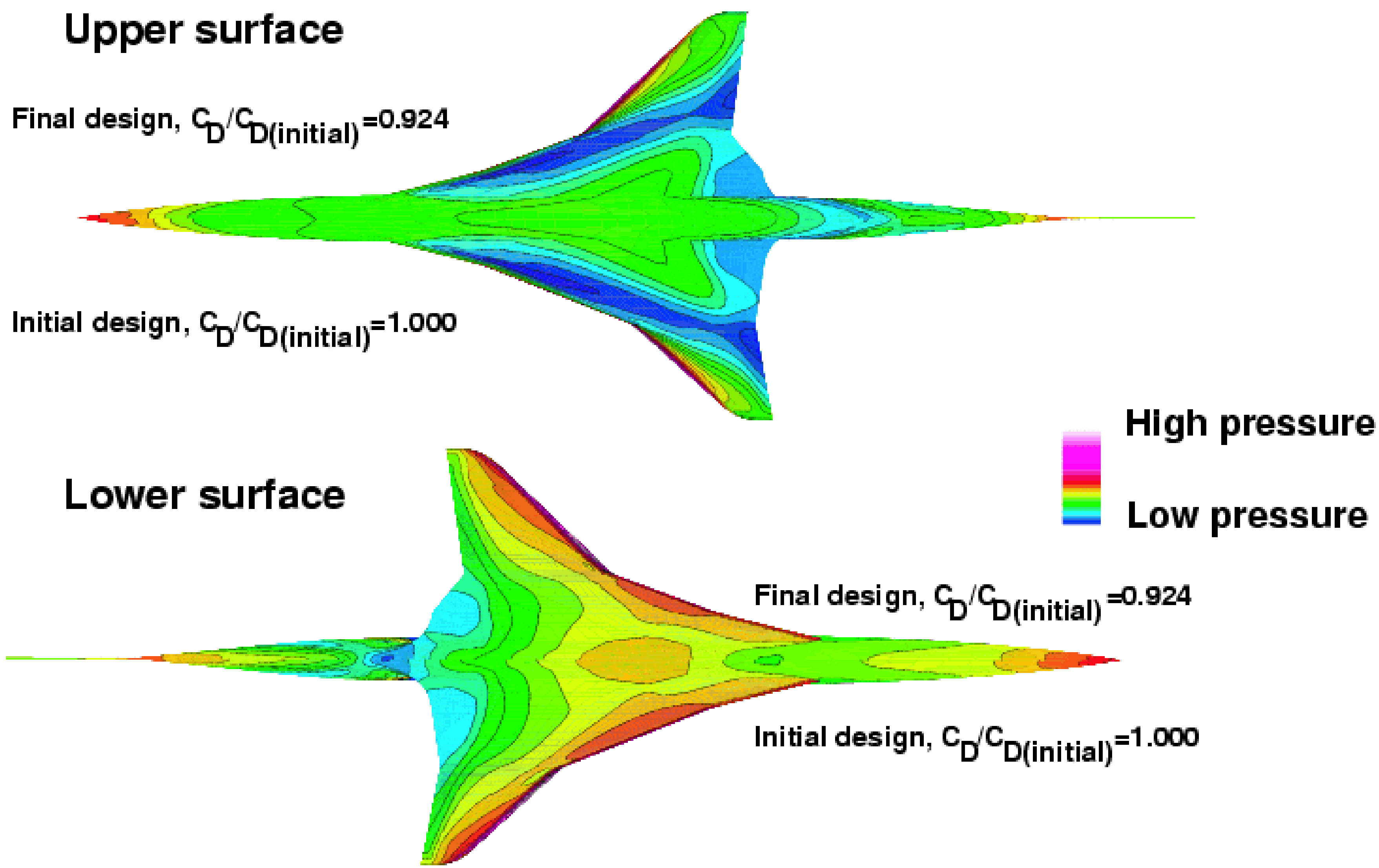
FE Model

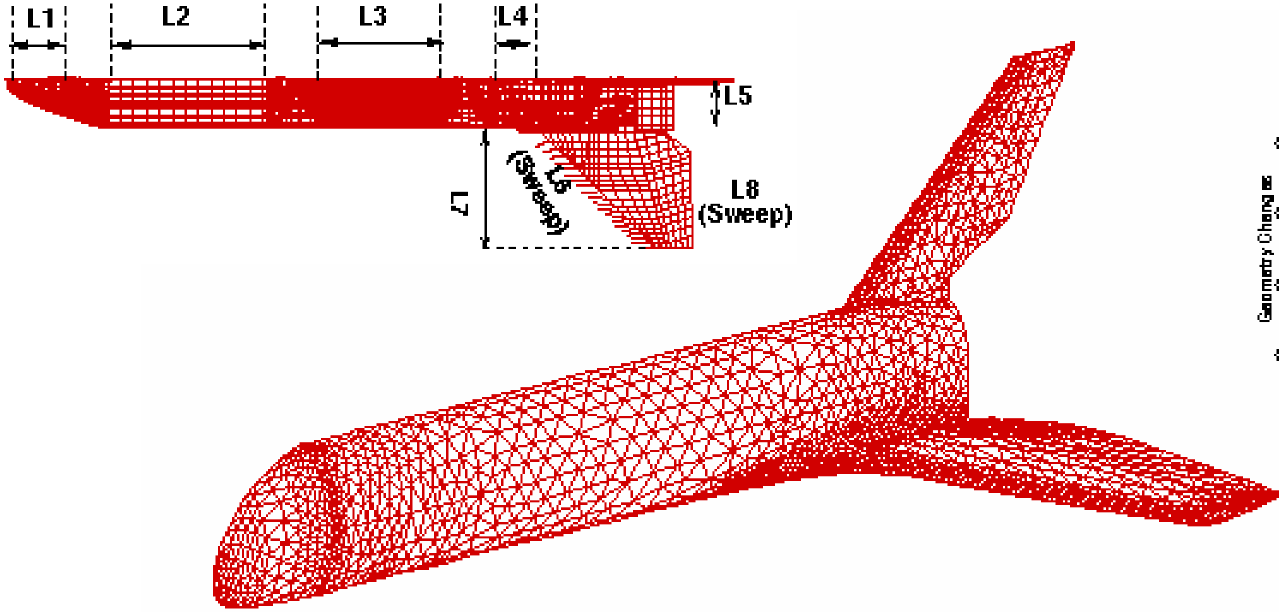


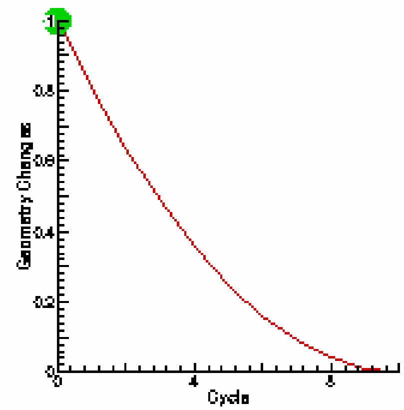
CFD Model

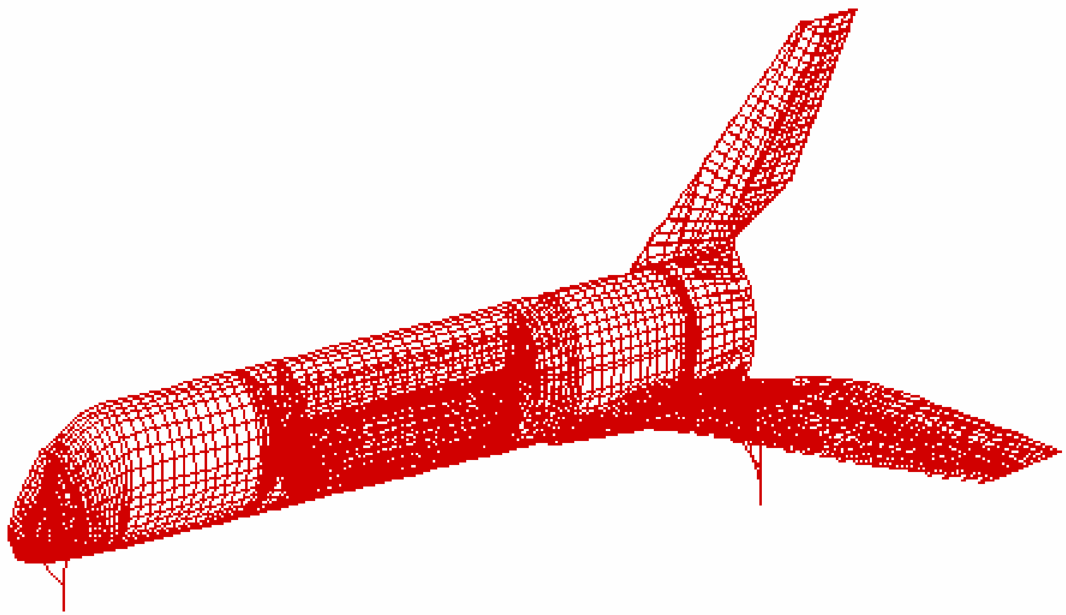
Nonlinear Aerodynamic Shape Optimization Results

Final design $C_D/C_{D(initial)}$=0.924, Fixed C_L









Shape Parameterization Tool for Aerospace Vehicle

MASSOUD's Pros & Cons

Pros

- Is Consistent
- No need for grid generation
- Easy to setup (hours)
- Parameterization is fast (seconds on OCTANE)
- Analytical sensitivity is available
- Has compact set of DVs
- Suitable for high- and low-fidelity applications

Cons

- Limited to small shape changes
- Fixed topology
- No built-in geometry constraints
- No direct CAD connection

ASCoT Project (1998-2002)
(Aerospace Systems Concept to Test)

Project Vision

Physics-based modeling and simulation with sufficient speed and accuracy for validation and certification of advanced aerospace vehicle design in less than 1 year

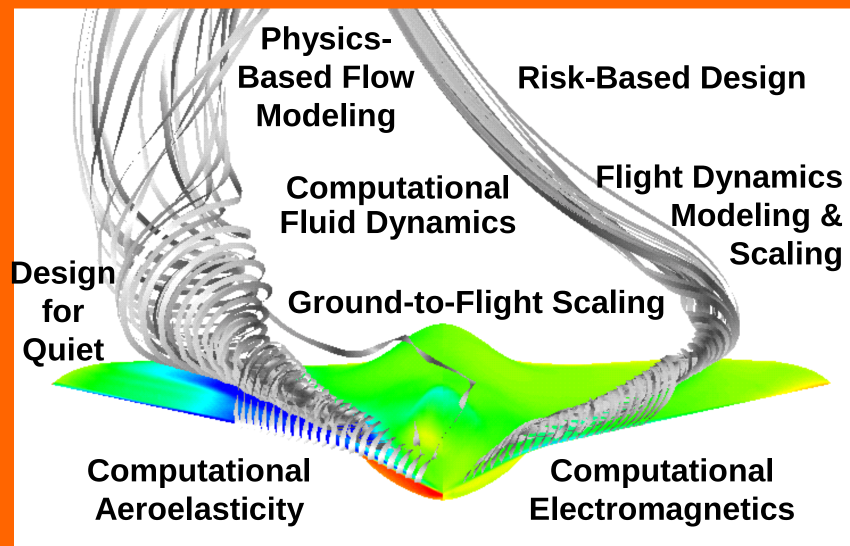
Project Goal

- **Provide next-generation analysis & design tools to increase confidence and reduce development time in aerospace vehicle designs**

Objective

- Develop **fast, accurate, and reliable** analysis and design tools via fundamental technological advances in:
  - Physics-Based Flow Modeling
  - Fast, Adaptive, Aerospace Tools (CFD)
  - Ground-to-Flight Scaling
  - Time-Dependent Methods
  - Design for Quiet
  - Risk-Based Design

Technology Areas



Benefit

- Increased Design Confidence
- Reduced Development Time

Challenges

- CAD-Based Shape Parameterization (ASCoT Project)
- Automation of geometry abstraction
- Automation of grid generation tools (Use of GUI should be limited to problem set up and monitoring phases)
- CAD-based sensitivity analysis, preferably analytical

References

- Samareh, Jamshid A., "Survey of Shape Parameterization Techniques for High-Fidelity Multidisciplinary Shape Optimization," AIAA Journal, May 2001, pp. 877-884.

- Jamshid A. Samareh: "Multidisciplinary Aerodynamic-Structural Shape Optimization Using Deformation", AIAA Paper No. 2000-4911.

- Samareh, J. A.: "Status and Future of Geometry Modeling and Grid Generation for Design and Optimization," J. Aircraft, Vol. 36, No. 1, Jan.-Feb. 1999, pp.97-104.

- Samareh, J. A., "A Novel Shape Parameterization Approach," NASA TM-1999-209116, Mar. 1999.